

J/ψ elliptic flow in relativistic heavy ion collisions

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The J/ψ elliptic flow in high energy nuclear collisions is calculated in a transport model. While the flow is very small at SPS and RHIC energies, it is strongly enhanced at LHC energy due to the dominance of the regeneration mechanism.

1. introduction

The J/ψ production is commonly accepted as a signature of the quark-gluon plasma formed in high energy nuclear collisions. The J/ψ elliptic flow which is sensitive to the early space-time evolution of the colliding system carries dynamic information on the new state of matter, if it is formed in the early stage. Since the recently observed J/ψ elliptic flow at RHIC energy [1] is with large uncertainty and can not differentiate from various J/ψ production mechanisms, it needs more precise experimental and theoretical studies.

The charm quark number in the partonic phase increases with the colliding nuclear energy. When the energy is high enough, the coalescence of those uncorrelated charm quarks becomes a significant source for J/ψ production. The J/ψ regeneration and its competition with the primordial J/ψ production have been discussed in different models [2, 3, 4]. To calculate the fractions of the initially produced and regenerated J/ψ s for the nuclear modification factor and transverse momentum distribution, we set up the charmonium transport equations [5] with both gain (regeneration) and lose (suppression) terms in the partonic phase. In this paper, we calculate the J/ψ elliptic flow in nuclear collisions at SPS, RHIC and LHC energies in the frame of the transport model.

2. transport model

Taking the fact that charmonia are heavy particles, the distribution function $f_\Psi(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b})$ where Ψ stands for $J/\psi, \chi_c$ and ψ' in transverse phase space at mid-rapidity can be described by a Boltzmann equation [5]

$$\partial f_\Psi / \partial \tau + \mathbf{v}_\Psi \cdot \nabla f_\Psi = -\alpha_\Psi f_\Psi + \beta_\Psi, \quad (1)$$

where $\mathbf{p}_t, \mathbf{x}_t, \tau$ and \mathbf{b} are respectively the charmonium transverse momentum, transverse coordinate, invariant time and impact parameter, $\mathbf{v}_\Psi = \mathbf{p}_t/E_\Psi$ is the charmonium transverse velocity, α and β are dissociation and regeneration rate calculated from the gluon dissociation process $\Psi + g \rightarrow c + \bar{c}$ and the reverse process. From the large single electron

elliptic flow measured at RHIC [6], charm quarks are supposed to be kinetically thermalized in the hot medium. The temperature, baryon chemical potential and medium velocity appeared in the gluon and charm quark thermal distributions are determined from the 2+1 dimensional ideal hydrodynamics. Solving the coupled transport equation for J/ψ and the hydrodynamic equations for the space-time evolution of the partonic phase, one can obtain the J/ψ distribution function $f_{J/\psi}(\mathbf{p}_t, \mathbf{x}_t, \tau|\mathbf{b})$ and in turn the nuclear modification factor R_{AA} and the averaged transverse momentum square [5].

3. J/ψ elliptic flow

The initially produced charmonia from nucleon-nucleon hard processes carry high momentum, and the gluon multi-scattering effect before the two gluons fuse into a charmonium leads to a further transverse momentum broadening [7]. Therefore, the high p_t J/ψ s in the final state are dominated by the initial production. On the other hand, the thermalized charm quarks in the hot medium satisfy the thermal distribution, and the regenerated charmonia are with low momentum and thus dominate the J/ψ production at low p_t region. The left panel of Fig.1 shows the fractions of initially produced and regenerated J/ψ s as functions of p_t for central Pb+Pb collisions at LHC energy. It is easy to see that the low p_t region is governed by regeneration and the high p_t region is characterized by initial production.

The elliptic flow v_2 describes the asymmetric degree of the particle momentum in transverse space, $v_2(p_t) = \langle p_x^2 - p_y^2 \rangle / p_t^2$. At SPS energy, there are only few charm quarks produced at the initial stage of the collisions. Therefore, the regeneration can be safely neglected. In this case, the initial production controls the system, and the non-thermalized J/ψ s can not feel the collective flow of the thermalized medium. The only source for the J/ψ elliptic flow is the leakage effect described by the free streaming term on the left hand side of the transport equation (1): J/ψ s with high p_t are easier to escape the hot medium in the direction where the fireball is thinner. Therefore, the final state J/ψ s are no longer isotropic and leads to finite value of v_2 . However, due to the expansion of the fireball, the asymmetry in geometry decreases with time, and the elliptic flow due to such geometry configuration is very small in comparison with the collective effect. We show on the right panel of Fig.1 the elliptic flow in heavy ion collisions at impact parameter $b = 7.8$ fm. At SPS, the elliptic flow is extremely small due to the lack of regeneration.

The fraction of regeneration for J/ψ increases with centrality monotonously. At RHIC, the regeneration becomes important and its contribution to the total J/ψ s is even around 50% in central Au+Au collisions [4, 5]. However, for semi-central collisions where the elliptic flow reaches the maximum, the system is still controlled by the initial production and the J/ψ elliptic flow is still very weak, as showed in the right panel of Fig.1.

The situation at LHC is very different. The formed fireball is much larger, hotter and longer lived, almost all the initially produced J/ψ s at low and intermediate momentum are eaten up by the medium, and the J/ψ production with $p_t < 4$ GeV is dominated by the regeneration, see the left panel of Fig.1. In this case the J/ψ s from the recombination of thermalized charm quarks carry large elliptic flow, and the maximum value at about $p_t \sim 4$ GeV reaches 10%. We have assumed charm quark thermalization at any p_t , the elliptic flow from the regeneration thus increases monotonously with p_t . While this is

not true at high p_t , it does not change the full v_2 remarkably, since the high p_t region is dominated by the initial production. Note that the shape of the J/ψ $v_2(p_t)$ is quite different from what observed for light quark hadrons [8] which is saturated at high p_t .

In summary, the J/ψ elliptic flow at LHC is expected to be much larger than that at SPS and RHIC, due to the dominance of the regeneration mechanism and the full thermalization of charm quarks.

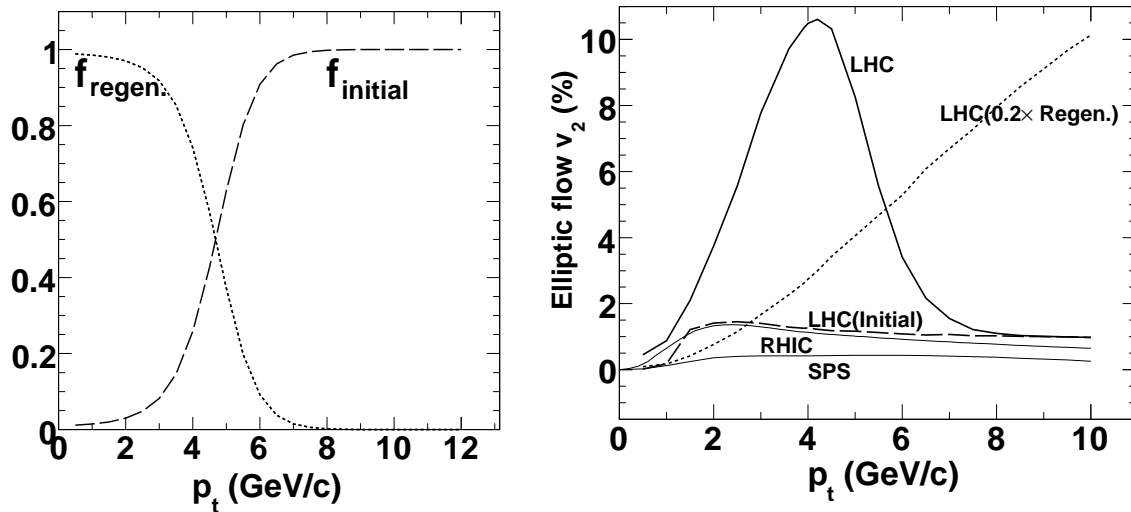


Figure 1. The J/ψ production fractions (left panel) and elliptic flow (right panel) as functions of transverse momentum in Pb+Pb collisions at impact parameter $b = 7.8$ fm at LHC energy. The calculations with only initial production, only regeneration (multiplied by a factor of 0.2) and both are indicated respectively by dashed, dotted and solid lines. The full elliptic flow at SPS and RHIC are also showed as a comparison.

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